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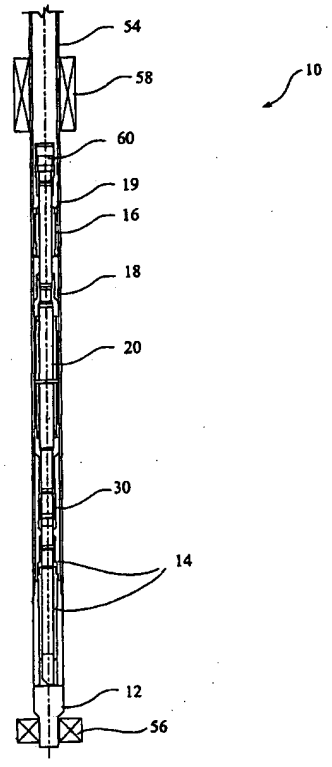
(54) Title: METHOD AND APPARATUS FOR WELLBORE SEPARATION OF HYDROCARBONS FROM CONTAMINANTS WITH REUSABLE MEMBRANE UNITS CONTAINING RETRIEVABLE MEMBRANE ELEMENTS



(57) Abstract: A retrievable separation system (10) for separating hydrocarbons from contaminants is positioned inside a production tubing or casing (54) in the wellbore of a well and can be easily retrieved by a retrieval tool without the removal of the entire production string. The retrievable separation system includes one or more membrane units (20 or 110) and shear-out subs (30) which are retrievable with a grasping portion of a retrieval tool. The membrane unit (20) may include reusable hardware (112,114,116, and 118) to house a replaceable membrane (130). New membranes (130) may be used to replace spent membranes with the membrane unit (20) being reinstalled in a wellbore for further separation of hydrocarbons from contaminants.

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METHOD AND APPARATUS FOR WELLBORE SEPARATION OF HYDROCARBONS FROM CONTAMINANTS WITH REUSABLE MEMBRANE UNITS CONTAINING RETRIEVABLE MEMBRANE ELEMENTS

FIELD OF THE INVENTION

The invention relates to recovery of hydrocarbons from a wellbore, and more particularly, the invention relates to technology for separation of contaminants from hydrocarbons in a wellbore with reusable hardware containing retrievable membrane elements.

BACKGROUND OF THE INVENTION AND BRIEF DESCRIPTION OF THE RELATED ART

Hydrocarbon gases and liquids have been recovered from underground wellbores for over a hundred years. The recovery technology generally involves drilling a wellbore into a hydrocarbon gas or liquid formation and withdrawing the materials under reservoir pressure or by artificial lifting.

The current recovery technology involves removing the hydrocarbons and any contaminants which are present from the wellbore together, and separating the contaminants from the hydrocarbons above ground. This above ground separation is costly. Disposal of the removed contaminants may also present environmental problems. The contaminants which may be produced include gases, such as carbon dioxide, nitrogen, water vapor, hydrogen sulfide, helium, and other trace gases, and liquids such as water, and others.

The contaminants which are brought to the surface and separated from the hydrocarbon must be released to the atmosphere or otherwise disposed of adding additional expense to the process. Due to environmental concerns about the release of greenhouse gases, many countries are placing greater and greater limitations on emission of byproduct gases to the

atmosphere. For example, some countries now assess a tax on carbon dioxide emissions. Other contaminants are highly corrosive or poisonous and require special handling. For example, hydrogen sulfide must be reacted and converted to molten sulfur before disposal.

Accordingly, it would be highly desirable to maintain some or all of the contaminant materials within the wellbore and/or selectively separate the contaminants in the wellbore for reinjection, removal, or other processing.

Membrane technologies have been developed which allow the selective passage of materials. This technology has heretofore been used as a surface technology for separating hydrocarbons from contaminants after recovery and has not been used in a downhole situation. It would be desirable to provide an apparatus and method for downhole separation and selective recovery to maximize the production of a desired hydrocarbon while minimizing production or separately producing contaminants.

U.S. Patent No. 6,015,011 describes a downhole hydrocarbon separator using membranes. The separator includes a permeable filter attached to the bottom of a packer so that a filter outlet end is in fluid communication with an aperture in the packer. The filter selectively passes fluids from beneath the packer to above the packer. However, when filters or membrane materials are used downhole for the filter materials can become fouled over time. The fouled filters greatly decrease the efficiency of the system.

It would be desirable to provide a downhole separation system in which the separating membranes or filters are retrievable for replacement or cleaning of the system. However, in the system of U.S. Patent No. 6,015,011, the entire well casing, packer, and filter must be removed for replacement or cleaning of the filter. This results in lost productivity and substantial downtime for replacement of a fouled filter.

Accordingly, it would be desirable to provide a system and method for quickly and easily retrieving and replacing downhole membranes.

SUMMARY OF THE INVENTION

The present invention provides a quick and reliable solution to retrieval and replacement of downhole membranes. The system includes a membrane system which is positioned within the production tubing or casing of a wellbore and can be removed from the wellbore independent of the production tubing.

In accordance with one aspect of the present invention, a retrievable system for separating hydrocarbons and contaminants in a wellbore includes a plurality of membrane units configured to be positioned in the wellbore for separating contaminants from a hydrocarbon. The membrane units each have a first end and a second end configured to be connected to the first end of another membrane unit. A shear-out member has first and second ends configured to be connected to first and second ends of the membrane units for interconnecting membrane units. The shear out member includes a shearing portion which shears at a predetermined load separating the first and second ends of the shear-out member.

In accordance with another aspect of the present invention, a retrievable system for separating hydrocarbons and contaminants in a wellbore includes a production tubing configured to be positioned in a wellbore, and at least one membrane unit configured to be positioned in the production tubing for separating contaminants from hydrocarbon. The membrane unit has a fishing neck located at one end to allow retrieval of the membrane unit from the production tubing with a retrieval tool.

In accordance with a further aspect of the present invention, a method of retrieving a system for separating hydrocarbons and contaminants in a wellbore includes the steps of providing a membrane separation system for separating hydrocarbons and contaminants in a wellbore, the membrane separation system including at least one membrane unit and at least one shear-out sub connected to the membrane unit; and removing the membrane units from a production tubing in the wellbore with a retrieval tool which grasps the membrane units.

In accordance an additional aspect of the present invention, a retrievable membrane unit having a replaceable membrane for separating hydrocarbons and contaminants in a wellbore includes a perforated tube configured to be positioned in the wellbore, a first end cap removably secured on a first end of the perforated tube, the first end cap including a coupling element for coupling the perforated tube to elements of the separation system, and at least one membrane removably secured in the perforated tube for separating contaminants from a hydrocarbon, wherein the membrane can be removed from the perforated tube by removing the first end cap.

In accordance with yet another aspect of the present invention, a method of replacing a membrane in a downhole system for separating hydrocarbons and contaminants includes the steps of: providing a membrane separation system for separating hydrocarbons and contaminants in a wellbore, the membrane system including a membrane unit containing a membrane; removing the membrane unit from the wellbore with a retrieval tool; removing the membrane from the membrane unit; replacing the membrane; and reinserting the membrane unit into the wellbore.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in greater detail with reference to the preferred embodiments illustrated in the accompanying drawings, in which like elements bear like reference numerals, and wherein:

FIG. 1 is a side cross sectional view of a downhole apparatus for separating hydrocarbons and contaminants according to the present invention;

FIG. 2 is an exploded side cross sectional view of a portion of the downhole apparatus for separating hydrocarbons and contaminants of FIG. 1;

FIG. 3 is an enlarged side cross sectional view of a shear-out sub of the apparatus of FIG. 1;

FIG. 4 is an enlarged side cross sectional view of a fishing neck sub of the apparatus of FIG. 1;

FIG. 5 is an enlarged side cross sectional view of a packoff assembly of the apparatus of FIG. 1;

FIG. 6 is an enlarged side cross sectional view of a latch-in seal assembly of the apparatus of FIG. 1;

FIG. 7 is an exploded side cross sectional view of the latch-in seal assembly of FIG. 6;

FIG. 8 is a side cross sectional view of a first end of a reusable membrane unit, which may be used in place of a membrane unit shown in FIG. 1, containing a membrane for separating hydrocarbons and contaminants according to the present invention;

FIG. 9 is a side cross sectional view of a second end of the reusable membrane unit for separating hydrocarbons and contaminants according to the present invention;

FIG. 10 is a schematic side cross sectional view of two interconnected reusable membrane units positioned downhole; and

FIG. 11 is a perspective view of a membrane having end seals.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Downhole membrane separation systems are used for separating contaminants from hydrocarbon liquids and gases downhole. The contaminants which are removed downhole may be reinjected into an underground disposal formation or removed to the surface for disposal. Over time, the membranes that are used downhole may become fouled due to accumulation of contaminants. In addition, the production of a particular well may change over time requiring a change in the configuration of the membrane separation system which is used. The present invention provides a system which allows membranes to be removed from a wellbore and replaced in an efficient manner.

Wells generally include a production tubing string or casing which is lowered into the well. The production tubing string may include valves, packers, and other elements for controlling the production of the well. The

production tubing string may also include membranes for separation of hydrocarbons and contaminates. However, in order to remove and replace membranes incorporated in the production string, the production string must be withdrawn from the well. This removal of the production string results in substantial downtime and expense.

The present invention provides a retrievable membrane separation system 10, shown in FIG. 1. The membrane separation system 10 is placed inside the production tubing (not shown) of a well and can be easily deployed by a deployment tool and retrieved by a retrieval tool without the removal of the entire production string.

FIG. 1 illustrates a membrane separation system 10 for separating hydrocarbons from contaminants in a wellbore. The system 10 includes a bottom sub 12, a seal assembly 14, one or more shear-out subs 30, one or more membrane units 20, a packoff assembly 16, and a fishing neck 60. The system may also include outer tubular members including a perforated liner 18, a packoff bushing 19, and a tube 54 for delivery of the hydrocarbon to the surface. The assembled separation system 10 is inserted inside the production tubing of a well and the bottom sub 12 is inserted into a packer 56 in the production tubing. An optional upper packer 58 may be added for isolation of the separated contaminants if the contaminants are to be disposed of downhole.

FIG. 1 illustrates a single membrane unit 20 for purposes of illustration. However, the membrane separation system 10 may include multiple membrane units 20 interconnected to one another and to one or more of the shear-out subs 30.

In an assembled configuration, each of the membrane units 20 includes one or more membranes (not shown) positioned inside the membrane unit. Each of the membranes separates one or more hydrocarbon and one or more contaminant. The membranes are hollow tube membranes positioned inside each of the membrane units 20. The membrane units 20 are connected to one another and to one or more of the shear-out subs 30 to

form the separation string or system 10 which is inserted into the production tubing in the wellbore.

The membrane units 20, as shown in FIG. 2, each include a hollow perforated tube having a first end 22 configured with interior threads and a second end 24 with exterior threads which is configured to mate with and engage a first end 22 of another membrane unit, a first end of a shear-out sub 30, or another sub. The shear-out sub 30 also has a first end 32 with interior threads and a second end 34 with exterior threads. The first end 32 of the shear-out sub 30 connects to the second end 24 of the membrane units 20, or another sub. The second end 34 of the shear-out sub 30 is arranged for mating engagement with the first end 22 of a membrane unit 20, or another sub. The first and second interconnecting ends of the membrane units 20 and the shear-out subs 30 allow the arrangement of the membrane units, shear-out subs, and other subs in a string as needed for a particular application. The entire membrane unit string can be removed from the wellbore as one piece or in multiple parts with the membrane units 20 separated at the shear-out subs 30 as described below.

The shear-out sub 30 is provided for severing the tubing string between the membrane units or between other units when the tubing string is subjected to excessive loads. This prevents the membrane units 20 from breaking within the wellbore when a portion of the string becomes stuck in the wellbore. Broken membrane elements 20 or other broken units left in the wellbore can cause significant functional problems and downtime for the well.

FIG. 3 illustrates one example of a shear-out sub 30 including first and second telescoping members 42, 44. The telescoping members 42, 44 are connected by a plurality of shear-out screws 46 or pins. The first telescoping member 42 fits inside the second telescoping member 44 and includes one or more annular grooves containing sealing elements 48. The sealing elements 48 may be O-rings, gaskets, or other known seals. The second telescoping member 44 of the shear-out sub 30 includes a fishing neck 50 which is configured to be grasped by a wireline retrieval tool (not shown). If the shear-

out screws 46 break due to excessive force being applied during removal of the membrane elements 20, the fishing neck 50 becomes exposed and allows a grasping portion of the retrieval tool to be connected to the remaining portion of the shear-out sub 30 for removal of membranes remaining in the wellbore. The shear-out sub 30 shears off at a predetermined tension load which is less than the load which would fracture the membrane units 20 or the other subs. In other words, a tensile strength of the shear-out subs 30 is less than a tensile strength of the membrane units 20 and the other subs in the separation string 10.

The membrane unit 20 as described above includes an outer rigid tube with perforations 26 and one or more membranes contained in the tube. The membrane unit 20 may also be formed with the membranes providing a self-supporting tube. However, the membrane unit 20 including a rigid perforated outer shell helps prevent breakage of the membrane unit during removal. One example of an alternative membrane unit 110 having a reusable perforated outer tube and replaceable membrane will be described below in more detail in conjunction with FIGS. 8-11.

The string of membrane units 20 is positioned within the production tube with the bottom sub 12 connected to the packer 56 in a known manner. For example, the bottom sub may be fixed in the packer 56 by a sealed connection including chevron seals, a snap latch connection, or other known connection. According to one embodiment of the invention, the string is connected to production packers at both ends.

FIG. 4 illustrates a fishing neck sub 60 which is attached to an upper end of a membrane unit 20 for retrieval of the membrane string. In particular, the fishing neck sub 60 includes a fishing neck 62 configured to be grasped by the retrieval tool. The fishing neck configuration illustrated in FIG. 4 is only one example a fishing neck. Other fishing neck configurations are known to those skilled in the art. The fishing neck sub 60 includes external threads 64 connectable to the internal threaded portion 22 of the membrane unit 20 or another sub. Although the fishing neck sub 60 has been described as a

separate sub connectable to the membrane units 20, the fishing neck portion may also be incorporated in one or more of the membrane units 20 or other subs.

FIG. 5 illustrates a packoff assembly 16 for use in the separation string 10 according to the present invention. The packoff assembly 16 is provided with an annular sealing portion 66 for preventing contaminants which have passed out through the walls of the membrane units 20 from entering the tube 54 which delivers the hydrocarbon to the surface.

FIGS. 6 and 7 illustrate one example of a latch-in seal assembly 14 for securing the inner members of the separation string to the outer tubular members of the separation string and for isolating the separated contaminant from the hydrocarbon passing through the separation string. The latch-in seal assembly 14 includes an outer latch-in seal housing 70 which is connected at one end to the bottom sub 12 and at an opposite end to the perforated liner 18. The latch-in seal assembly 14 also includes an inner assembly 72 positioned in the outer housing 70. The inner assembly 72 is connected at one end to inner elements of the membrane string, such as the shear-out sub 30 or membrane units 20. The inner assembly 72 ratchets into the outer housing 70 in the manner described below to latch the inner assembly 72 and connected inner units to the outer housing 70 and connected outer units.

The inner assembly 72, as shown more clearly in FIG. 7, includes a top sub 74, a mandrel 76, a latch member 78, a packing assembly 80, and a shoe sub 82. The latch member 78 includes a plurality of flexible threaded fingers 84 which allow the inner assembly 72 to be ratcheted into a latch-in thread 86 of the outer housing 70 to secure the inner assembly in the outer housing. The inner assembly 72 is removable from the outer housing 70 by unscrewing. The inner assembly 72 can also be uncoupled from the outer housing 70 by pulling the inner assembly 72 with so predetermined load which causes flexing of the fingers 84. The latch member 78 having the fingers 84 is secured between the mandrel 76 and the top sub 74 which are threaded together.

The packing assembly 80 includes chevron seals or other seals for preventing fluid from passing between the inner and outer assemblies of the membrane string to isolate the removed contaminant from the hydrocarbon. The packing assembly 80 is secured on the mandrel 76 by threading the shoe sub 82 onto the mandrel.

Although the latch-in seal assembly 14 has been illustrated with a ratchet together/thread apart connection, it should be understood that other known connections, such as snap rings may also be used. In addition, the chevron seals are just one examples of the seals which may be used.

The separation string according to the present invention is assembled by screwing the membrane elements 20, shear-out subs 30, fishing neck sub 60, inner latch-in seal assembly 72, packoff assembly 16, and any other inner subs together in a configuration which is selected depending on the properties of a particular well. The outer tubular members including the packoff bushing 19, perforated liner 18, tube 54, outer housing 70 of the seal assembly 14, and the bottom sub 12 are also threaded together. The inner members are then inserted into the outer tubular members with the latch-in seal assembly 14 snapping or ratcheting the inner and outer members together. Once the inner and outer members are secured together, the inner members are prevented from floating out or otherwise becoming disconnected from the outer tubular members during operation.

Although the parts of the separation string 10 have been illustrated with threaded connections, it should be understood that other known connecting mechanisms may also be used. The assembled separation string is lowered into a production tubing with a conventional deployment tool and sealed in place with appropriate packers. The deployment tool may be a wireline, coiled tubing, tubing, or other deployment tool.

FIGS. 8 and 9 illustrate the top (first) and bottom (second) ends of an alternative embodiment for a membrane unit 110 for separating hydrocarbons from contaminants in a wellbore. Membrane unit 110 may be used in place of membrane unit 20 described above. Membrane unit 110 includes an outer

perforated tube 112, an inner perforated tube 114, and first and second end caps 116, 118. A tubular membrane 130 is received and supported between the outer and inner perforated tubes 112, 114.

The first end cap 116, as shown in FIG. 8, includes a connecting end with internal threads 132 for connection to other membrane elements, shear-out subs, production packers, or other elements of the separation system. The first end cap 116 also includes a membrane end including a first set of internal threads 134 for threaded connection of the end cap to the outer tube 112 and a second set of internal threads for connecting the end cap to the inner tube 114.

The second end cap 118, as shown in FIG. 9, includes a connecting end with external threads 138 for connection to other elements in the separating string, such as membrane elements and shear-out subs. The second end cap 118 also includes internal threads 140 for connection to the outer tube 112. A sealing member 142, such as one or more O-rings or gaskets, is provided for sealing the inner tube 114 to the second end cap 118. The positions of the sealing member 142 and internal threads 136 sealing between the end caps 116, 118 and the inner tube 114 may also be reversed.

The end caps 116, 118 of the membrane unit 110 allow the membrane 130 to be removed from the membrane unit and replaced when the membrane becomes fouled. For replacement of the membrane 130, one or both of the end caps 116, 118 may be removed. The membrane unit 110 is illustrated with inner and outer perforated tubes 114, 112 for providing structural support for the membrane 130. The membrane 130 is illustrated sandwiched between the inner and outer tubes 114, 112. However, either the inner or outer tube 114, 112 may be omitted if the membrane 130 is sufficiently self-supporting.

The outer tube 112 preferably has a tensile strength which is sufficient to carry a load provided by the elements in the separation string which are located below the membrane unit 110 and are interconnected to each other and to the membrane unit. When a shear-out sub is provided, the tensile

strength of the outer tube 112 is greater than the tensile strength of the shear-out sub. The outer tube 112 also provides protection of the membrane from wear as the membrane unit 110 is run into the well. The inner tube 114 provides protection of the membrane 130 from wear which may occur when tools are passed through the center of the membrane.

The ends of the membrane 130 may be provided with sealing rings 150, 152 as shown in FIG. 11. The sealing rings 150, 152 are formed of a malleable material, such as plastic. The sealing rings 150, 152 are trapped between the inner tube 114 and the end caps 116, 118 with a press fit and provide a seal between the membrane 130 and the end caps. This prevents the flow of fluid around the ends of the membrane 130. For example, the sealing rings 150, 152 will prevent fluid which has passed out through the membrane 130 from flowing back into the hydrocarbon stream passing through the center of the membrane unit 110. Alternative or additional sealing arrangements may also be provided. For example, the seals provided by the sealing rings 150, 152 can be enhanced by adding O-rings or other seals.

The membrane unit 110 has been illustrated with a single membrane 130, however, multiple membranes may also be positioned within one membrane unit. The membrane units 110 may be connected to one another, as shown in FIG. 10, and to other elements of a separation system by the threaded connectors 132, 138 on the ends of the membrane units. The membrane units 110 may be connected in series, parallel, or combinations thereof as needed for a particular application. One or more membrane units 110 and other units together form a separation string which is inserted into the wellbore.

The assembled separation string according to the present invention is lowered into a wellbore and sealed in place. The separation string may be positioned in a production tubing in the wellbore for easy retrieval without removing the entire production tubing.

The membrane units 110 have a tubular configuration and allow connection in a continuous string which has an open central passageway. This tubular configuration allows conventional oil field tools to be run through the membrane units. The ability to run tools through the membrane units 110 provides the added advantage that the membrane units do not have to be removed for many processes to be performed. For example, gas lift valves, setting and pulling tools, impression blocks, chemical injection valves, tubing stops, packers, tubing plugs, memory logs, production logs, dump bailers, perforation guns, or the like can be run through the membrane units 110. The membrane 130 is protected from wear as the tools are passed through the membrane unit 110 by the inner tube 114.

The operation of the present invention will be described with respect to a vertical well, however, it should be understood that the invention may be employed in horizontal wells and other non-vertical wells.

In operation, the hydrocarbon and contaminants enter the wellbore and pass upward through the inside of the membrane unit 110. As the hydrocarbon passes through the membrane unit 110, one or more contaminants permeate out through the membrane 130 and enter a surrounding containment collection zone. The hydrocarbon plus any remaining contaminants that were not removed continue out the top of the membrane unit 110. The hydrocarbon with reduced contaminants is passed to the surface or to another separation system. The contaminants which have been collected in the collection zone may be disposed of by directing the contaminants to an underground disposal formation. Alternatively, the contaminants may be removed from the collection zone to the surface.

When the membranes become fouled, an increase in the amount of contaminants produced may be observed at the surface indicating that the membranes should be replaced or cleaned. Other detection methods may also be used to detect fouling of the membranes. In addition to replacement of membranes when they become fouled, it may be desirable to replace membranes for other reasons, such as when the production of a well changes

and different membranes are needed for removal of different contaminants or when improved membrane technologies become available. The removed membranes may be cleaned for reuse or discarded.

The membrane units 110 may be removable and replaceable by a retrieval tool using conventional retrieval technology such as wireline or coil tubing. A wireline retrieval tool includes a grasping portion which grasps an end of the membrane unit 110 or a fishing neck which is attached to an end of the membrane unit. A fishing neck functions as a receptacle for the grasping portion of the retrieval tool.

The operation of the present invention will be described with respect to a vertical well, however, it should be understood that the invention may be employed in horizontal wells and other non-vertical wells.

In operation, the hydrocarbon and contaminants enter the wellbore and pass upward through the inside of the separation string 10 and the membranes which are positioned in the membrane units 20. As the hydrocarbon passes through the membranes, one or more contaminants permeate out through the membranes and enter a surrounding containment collection zone. The hydrocarbon plus any remaining contaminants that were not removed continue out the tops of the membrane tubes. The hydrocarbon with reduced contaminants is passed to the surface or to another separation system. The contaminants which have been collected in the collection zone may be disposed of by directing the contaminants to an underground disposal formation. Alternatively, the contaminants may be removed from the collection zone to the surface.

When the membranes become fouled, an increase in the amount of contaminants produced may be observed indicating that the membranes should be replaced. Other detection methods may also be used to detect fouling of the membranes. In addition to replacement of membranes when they have become fouled, it may be desirable to remove the separation system for alterations, modifications, or updates when the production of the well changes or when improved technologies become available.

The membrane units 20, or 110, may be removable and replaceable by a retrieval tool using conventional retrieval technology such as wireline or coiled tubing. A wireline retrieval tool includes a grasping portion which grasps the fishing neck sub 60 and pulls the separation string out of the production tubing. The fishing neck sub 60 functions as a receptacle for the grasping portion of the wireline retrieval tool. A coiled tubing retrieval system operates in a similar manner.

The wellbore and the production tubing in the wellbore may include curves and irregularities which can cause the separation string to become stuck during retrieval. If a portion of the separation string becomes stuck in the production tubing during removal, the shear-out sub 30 shears off at a predetermined tension load leaving the fishing neck 50 of the shear-out sub exposed. The retrieval tool is then lowered into the production tubing to retrieve a remainder of the separation string by grasping the fishing neck 50 of the shear-out sub 30. The removed membranes may be cleaned for reuse or discarded.

Some of the contaminants which may be removed are gases including carbon dioxide, nitrogen, water vapor, hydrogen sulfide, helium, and other trace gases, and liquids including water, and other liquids. In addition, heavy hydrocarbons may be separated from hydrocarbon gases. The hydrocarbon from which the contaminants are separated according to the present invention may be oil, methane, ethane, propane, or others.

Each one of the stacked membrane units 20 may be designed to permeate one or more of the contaminants which are present in the well. For example, one membrane unit 20 may be designed for removal of carbon dioxide, a second for removal of hydrogen sulfide, and a third for removal of water.

Although a hollow fiber or tubular shaped membrane formed of multiple membrane elements is illustrated, other membrane shapes may also be used. Some other membrane shapes includes spiral wound, pleated, flat sheet, or polygonal tubes. The use of multiple hollow fiber membrane tubes

have been selected for their large fluid contact area. The contact area may be further increased by adding additional tubes or tube contours.

The membrane units 20 may be stacked in different arrangements to removed contaminants from the flow of hydrocarbon gas in different orders. For example, the bottom membrane units 20 may be those that remove water and heavy hydrocarbons which may damage some of the membrane materials. The membrane units 20 may be arranged in series or parallel configurations or in combinations thereof depending on the particular application.

The separation system according to the present invention may be of a variable length depending on the particular application. The stacked membrane units 20 may even extend along the entire length of the wellbore for maximum contaminant removal.

FIG. 1 illustrates an inside-out flow path where the hydrocarbon and contaminants flow into the inside of the membrane tube(s) and the contaminant permeates out through the tube. However, an outside-in flow path may also be used where the hydrocarbon and contaminants flow around the outside of the tube(s) and the contaminants are permeated into the inner bore of the tube(s).

The membranes according to the present invention are selected to be durable, resistant to high temperatures, and resistant to exposure to liquids. The materials may be coated or otherwise protected to help prevent fouling and improve durability. Examples of suitable membrane materials for removal of contaminants from a hydrocarbon gas stream include cellulose acetate, polysulfones, polyimides, cellulose triacetate (CTA), carbon molecular sieve membranes, ceramic and other inorganic membranes, composites comprising any of the above membrane materials with another polymer, composite polymer and molecular sieve membranes including polymer zeolite composite membranes, polytrimethylsilene (PTMSP), and rubbery polymers.

Some examples of polyimides are the asymmetric aromatic polyimides in hollow fiber or flat sheet form. Patents describing these include U.S. Patent No. 5,234,471 and U.S. Patent No 4,690,873.

Some examples of carbon molecular sieve membranes are those prepared from the pyrolysis of asymmetric aromatic polyimide or cellulose hollow fibers. Patents describing these include European Patent Application 0 459 623 and U.S. Patent No 4,685,940. These fibers may be coated with a separate polymer or post-treated after spinning to increase resistance to high humidity and impurities, such as in U.S. Patent No. 5,288,304 and U.S. Patent No. 4,728,345.

The number, type, and configuration of the membranes may vary depending on the particular well. The separation system may be specifically designed for a particular well taking into account the type and amounts of hydrocarbon and contaminants present in the well, and the well configuration.

The present invention may be combined with existing downhole technologies for mechanical physical separation systems, such as cyclones or centrifugal separation systems. The invention may also be used for partial removal of the contaminants to reduce the burden on surface removal facilities with the remaining contaminants removed by conventional surface technologies. Some types of separated contaminants such as carbon dioxide can be reinjected into the productive horizon to maintain pressurization of the reservoir.

While the invention has been described in detail with reference to the preferred embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made and equivalents employed, without departing from the present invention.

WHAT IS CLAIMED IS:

1. A retrievable system positionable in a production tubing of a wellbore for separating hydrocarbons and contaminants in the wellbore, the system comprising:

a plurality of membrane units configured to be positioned in the wellbore for separating contaminants from a hydrocarbon, the membrane units each having a first end and a second end, the second end is configured to be connected to the first end of another membrane unit; and

a shear-out member for preventing fractures of the membrane units, the shear-out member having first and second ends configured to be connected to first and second ends of the membrane units for interconnecting membrane units, the shear out member having a shearing portion which shears at a predetermined load separating the first and second ends of the shear-out member and exposing a portion configured to be grasped by a retrieval tool, wherein the predetermined load at which the shearing portion shears is less than a load which would fracture the membrane units.

2. The system of Claim 1, wherein the shear-out member includes two telescoping members and the shearing portion connects the two telescoping members.

3. The system of Claim 2, wherein one of the telescoping members of the shear-out member includes the portion configured to be grasped by a retrieval tool when the shearing portion has been sheared.

4. The system of Claim 1, wherein at least one of the plurality of membrane units is provided with a fishing neck configured to be grasped by a retrieval tool.

5. The system of Claim 4, wherein the fishing neck is configured to be connected to the first end of the membrane units.

6. The system of Claim 1, further comprising first and second sealing assemblies for preventing contaminants which have been separated by the membrane units from passing back into a hydrocarbon stream.

7. The system of Claim 6, wherein the second sealing assembly provides a latch for securing the membrane units and shear-out subs within a perforated tubular liner.

8. A retrievable hydrocarbon separation system positionable in a production tubing for retrieval of the separation system without removal of the production tubing, the system comprising:

at least one membrane unit configured to be positioned in the production tubing for separating contaminants from hydrocarbon, the membrane unit having a fishing neck located at one end to allow retrieval of the membrane unit from the production tubing with a retrieval tool.

9. The system of Claim 8, wherein the fishing neck is coupled to the membrane unit by a releaseable coupling.

10. The system of Claim 8, wherein the at least one membrane unit switch positions comprises a plurality of membrane units connected to one another by releaseable couplings.

11. The system of Claim 10, further comprising a shear-out sub connected between the membrane units for preventing fracture of the membrane units, the shear-out sub having a sheared configuration which exposes a fishing neck of the shear-out sub for retrieval of the membrane units.

12. The system of Claim 8, wherein the at least one membrane unit is positioned within a perforated tubular liner and is connected to the perforated liner by a latch-in assembly.

13. A method of retrieving a system for separating hydrocarbons and contaminants in a wellbore without fracturing the system except a defined locations, the method comprising:

providing a membrane separation system for separating hydrocarbons and contaminants in a wellbore, the membrane separation system including at least one membrane unit and at least one shear-out sub connected to the membrane unit;

removing the membrane unit from a production tubing in the wellbore with a retrieval tool which grasps the membrane unit; and

shearing the separation system at the shear-out sub without fracturing of the membrane unit.

14. The method of Claim 13, further comprising the step of:

grasping and removing a remaining portion of the separation system with the retrieval tool by grasping a fishing neck of a remaining portion of the shear-out sub.

15. The method of Claim 14, further comprising servicing the membrane separation system and replacing the membrane separation system in the production tubing.

16 A retrievable and reusable membrane system having a replaceable membrane for separating hydrocarbons and contaminants in a wellbore, the system comprising:

a perforated tube configured to be positioned in the wellbore;

a first end cap removably secured on a first end of the perforated tube, the first end cap including a coupling element for coupling the perforated tube to elements of the separation system; and

at least one membrane removably secured in the perforated tube for separating contaminants from a hydrocarbon, wherein the membrane can be removed from the perforated tube by removing the first end cap.

17. A separation system having a replaceable membrane for separating hydrocarbons and contaminants in a wellbore, the separation system comprising:

a plurality of reusable membrane units configured to be positioned within a wellbore, the membrane units having connectors for interconnecting the membrane units to form a continuous flow path; and

at least one replaceable membrane in each of the reusable membrane units for separating hydrocarbons and contaminants.

18. The separation system of Claim 17, wherein the membrane units each include a perforated member containing the membrane and a removable cap which is removable for replacement of the membrane.

19. The separation system of Claim 18, wherein a passage is provided through the tubular perforated member and the tubular membrane suitable for passing tools.

20. A separation system having a replaceable membrane for separating hydrocarbons and contaminants in a wellbore, the system comprising:

an outer perforated tube for providing exterior structural support;

an inner perforated tube for providing wear protection; and

a membrane trapped between in the outer perforated tube and the inner perforated tube for separating hydrocarbons and contaminants in a wellbore.

21. The system of Claim 20, further comprising an end cap which is removable from the outer perforated tube for removing and replacing the membrane.

22. A method of replacing a membrane in a downhole system for separating hydrocarbons and contaminants, the method comprising:

providing a membrane separation system for separating hydrocarbons and contaminants in a wellbore, the membrane system including a membrane unit containing a membrane;

removing the membrane unit from the wellbore with a retrieval tool;

removing the membrane from the membrane unit;

replacing the membrane; and

reinserting the membrane unit into the wellbore.

23. The method of Claim 22, wherein the step of removing the membrane from the membrane unit includes removing an end cap from the membrane unit and removing the membrane from an open end of the membrane unit.

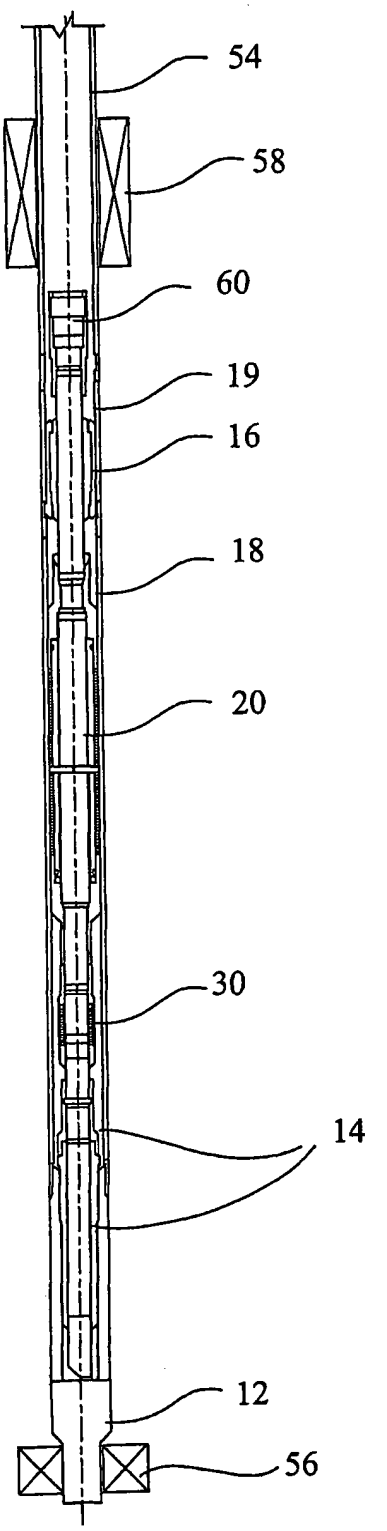

Fig. 1

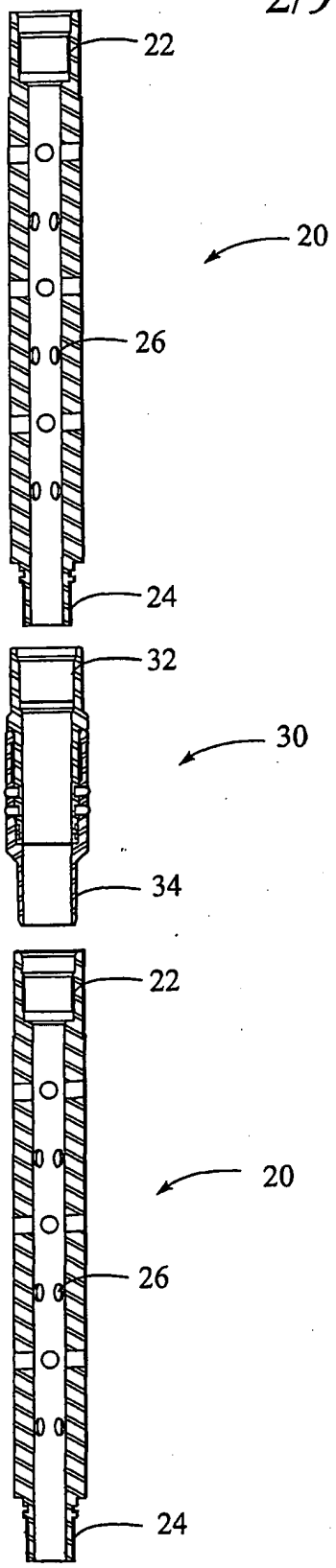

Fig. 2

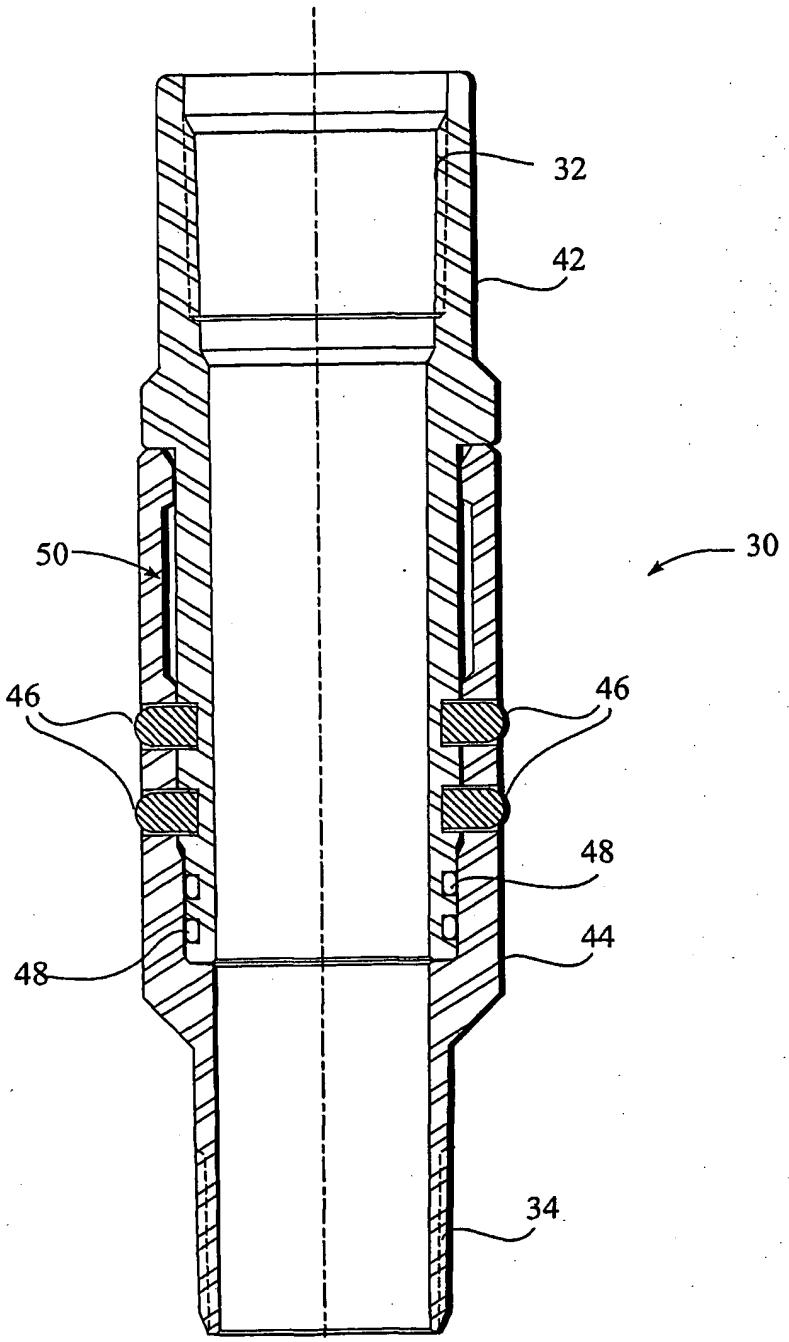

Fig. 3

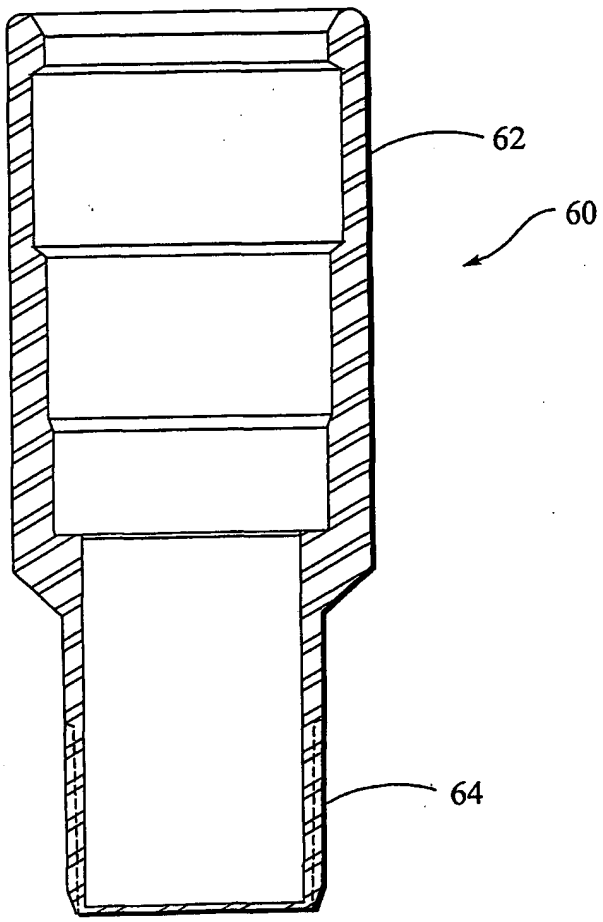

Fig. 4

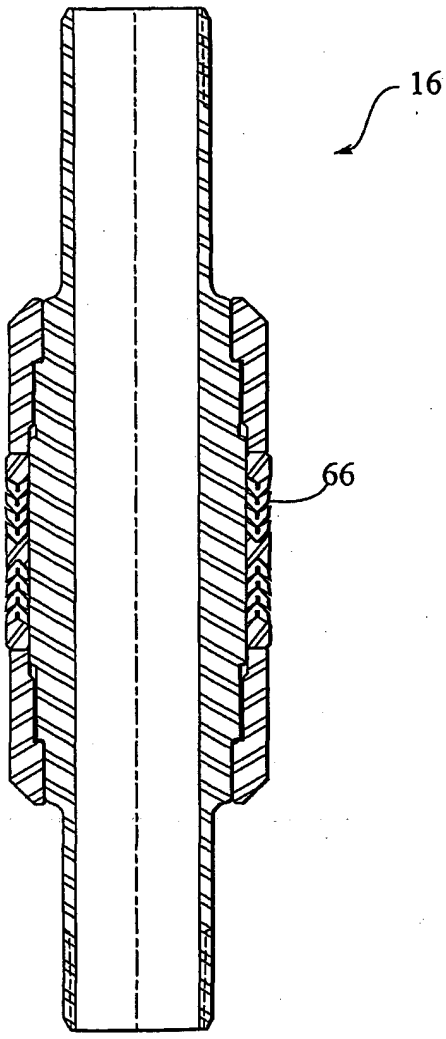

Fig. 5

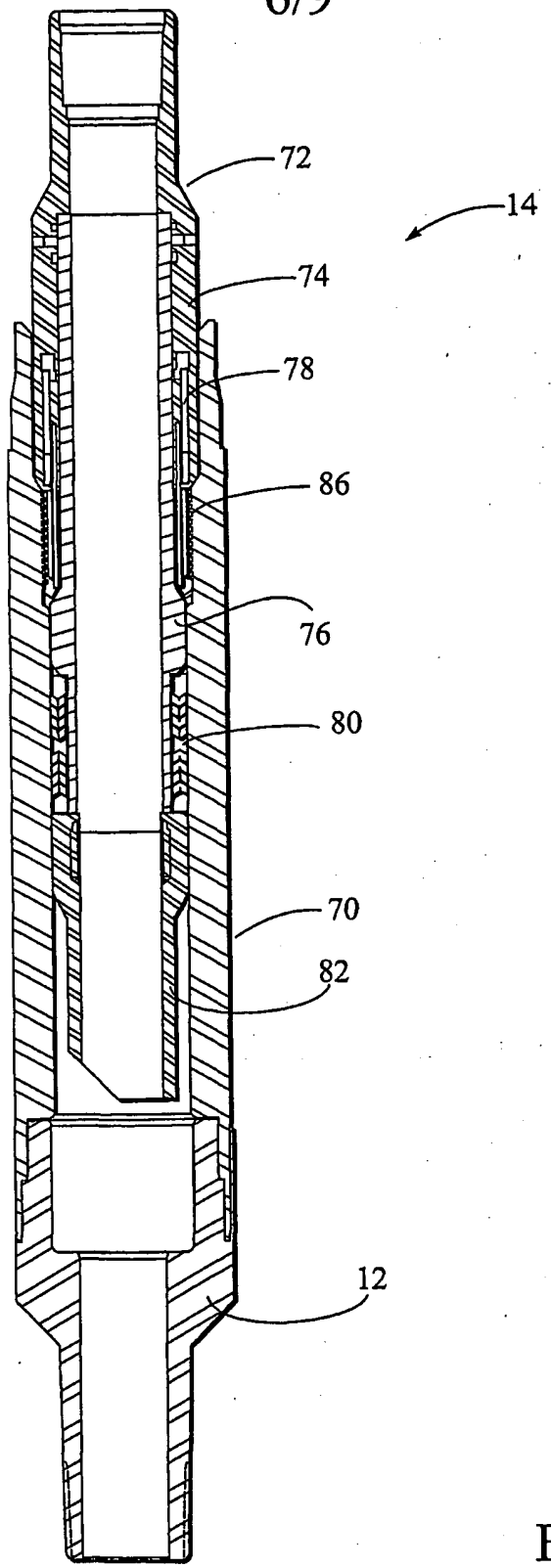

Fig. 6

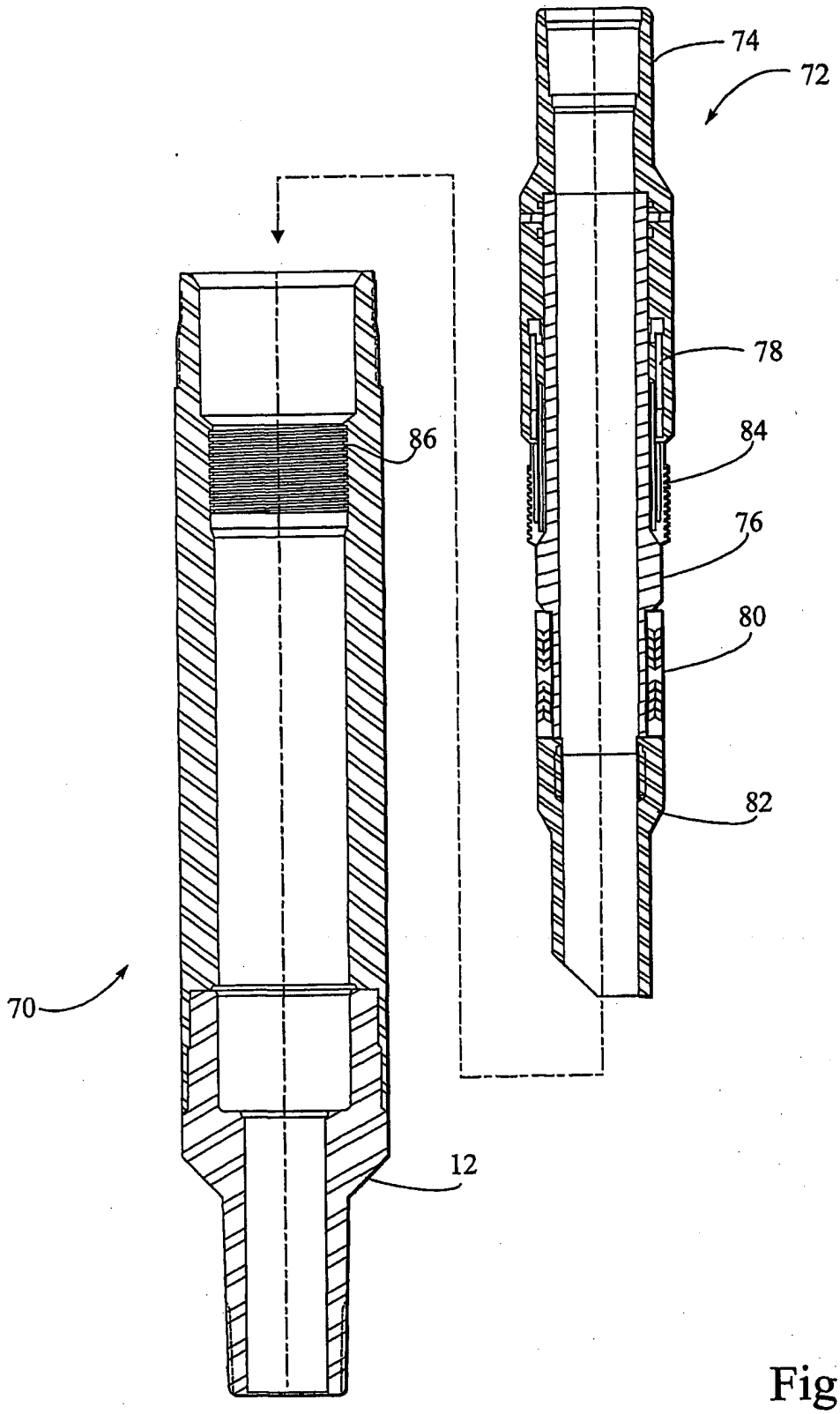

Fig. 7

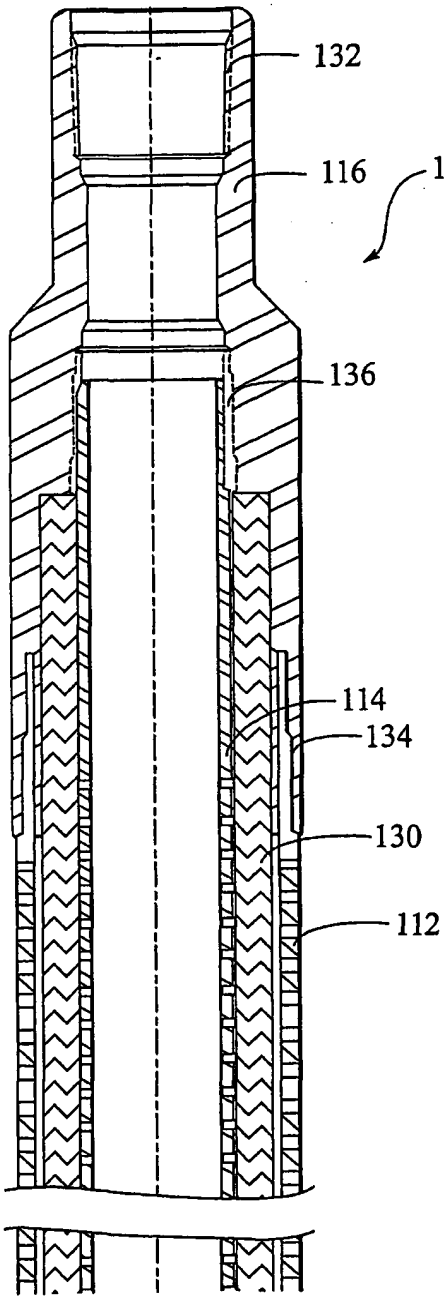

Fig. 8

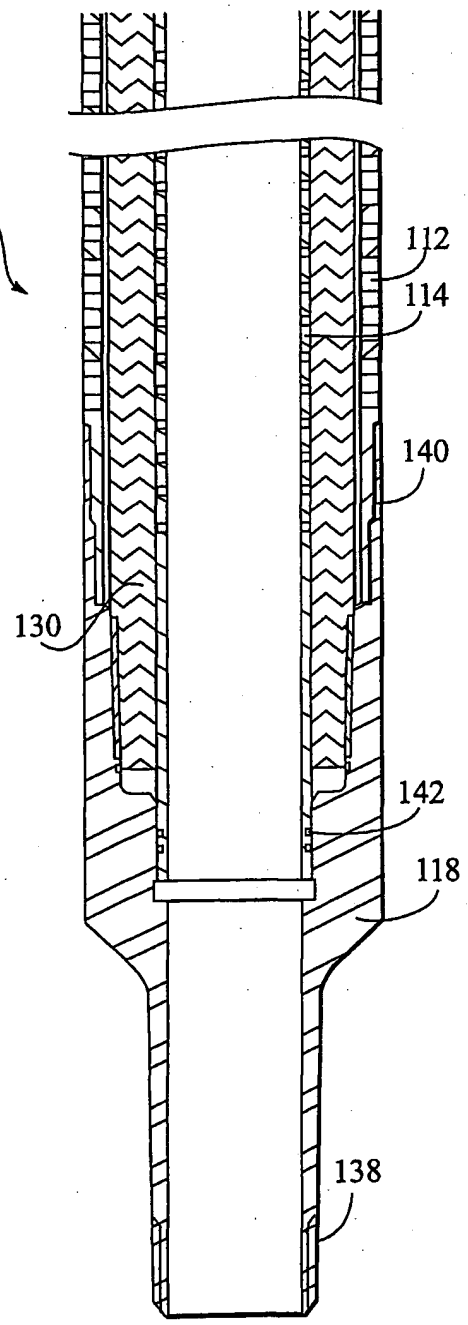

Fig. 9

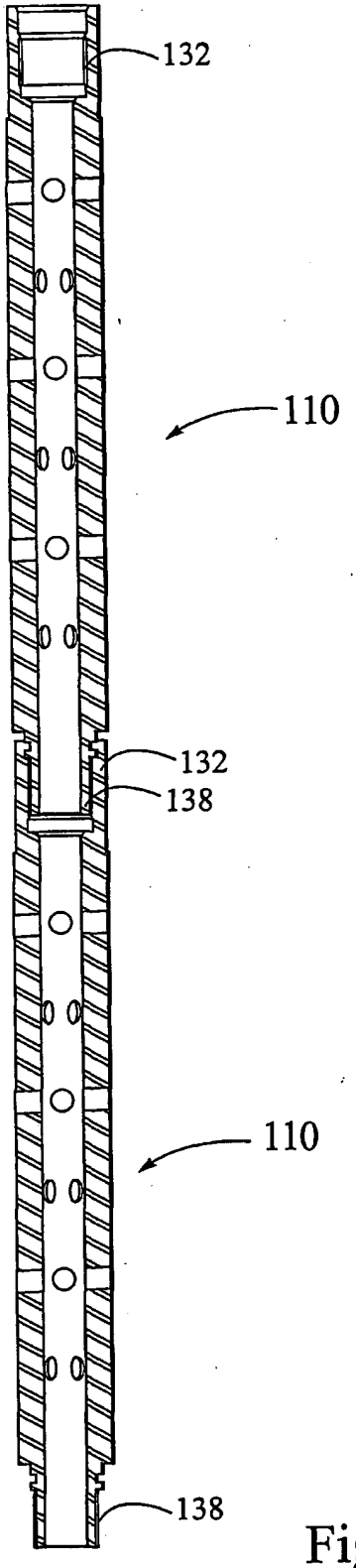

Fig. 10

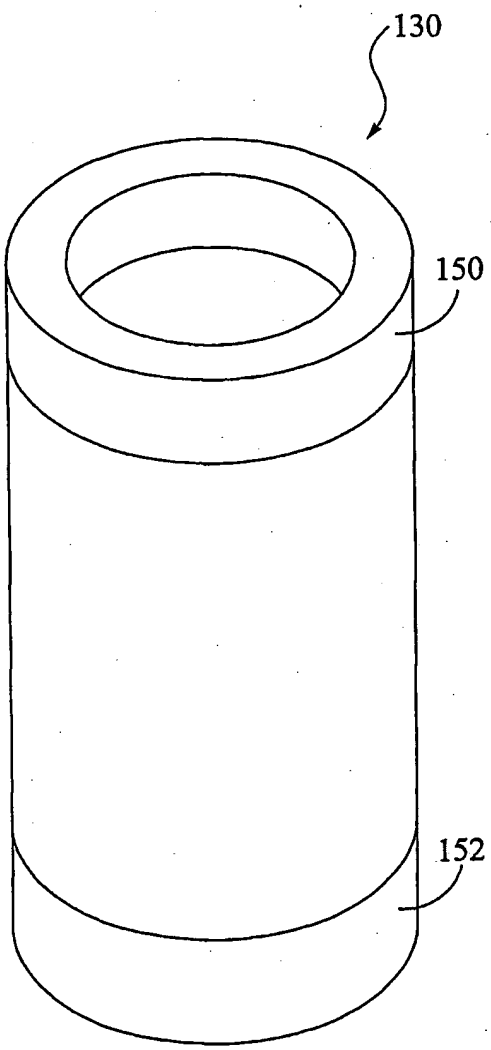

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/25545

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : E21B 17/08, 43/08, 43/38
US CL : 166/265,242.7,235,236
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 166/265,242.7,235,236,228,234,377,227,376,242.6; 201/323.1,323.2,330,338,341

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 5,762,137 A (Ross et al.) 09 June 1998 (09.06.1998), col. 1, lines 50-60, col. 2, lines 5-55, col. 3, line 40-col. 6, line 30, col. 7, lines 35-50, col. 8, line 55-col. 9, line 15, and col. 9, lines 55-65.	16-19, 22, 23 — 20 and 21
Y	US 5,992,518 A (Whitlock) 30 November 1999 (30.11.1999), col. 2, line 15-col. 3, line 15, col. 4, line30-col. 10, line 30, col. 24, line65-col.26, line 10, col. 28, line 60-col. 29, line 15, col. 30, line 35-col. 31, line 10, and col. 31, line 60-col. 32, line 30.	1-15
Y	US 5,188,182 A (Echols, III et al.) 23 February 1993 (23.02.1993), col. 4, lines 20-55, col. 7, line 45-col. 8, line10, and col. 9, lines 25-55.	1-15
Y	US 5,673,752 A (Scudder et al.) 07 October 1997 (07.10.1997), col. 2, lines 10-20 and col. line 55-col. 3, line 40, and Figure 2.	12,20,21
Y	US 5,860,476 A (Kjos) 19 January 1999 (19.01.1999), col. 1, line 55-col. 2, line 20, col. 2, line 55-col. 3, line 10, col. 3, line 55-col. 4, line 10.	6
Y	US 4,445,572 A (Fineberg et al.) 01 May 1984 (01.05.1984), col. 2, lines 20-45, col. 2, line 65-col. 3, line 25, col. 3, line 40-col. 5, line 35.	2-5
A	US 5,240,073 A (Bustamante et al.) 31 August 1993 (31.08.1993), see Abstract.	1-23

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search
03 October 2001 (03.10.2001)

Date of mailing of the international search report
30 OCT 2001

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/25545

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,823,260 A (McConnell et al.) 20 October 1998 (20.10.1998), see Abstract.	1-23
A	US 6,098,716 A (Hromas et al.) 08 August 2000 (08.08.2000), see Abstract.	1-23
A, P	US 6,158,507 A (Rouse et al.) 12 December 2000 (12.12.2000), see Abstract.	1-23
A	US 4,487,259 A (McMichael, Jr.) 11 December 1984 (11.12.1984), see Abstract.	1-23
A	US 4,693,318 A (Petrovic) 15 September 1987 (15.09.1987), see Abstract.	1-23
A	US 4,977,958 A (Miller) 18 December 1990 (18.12.1990), see Abstract.	1-23
A	US 5,310,000 A (Arterbury et al.) 10 May 1994 (10.05.1994), see Abstract.	1-23
A	US 5,551,513 A (Surles et al.) 03 September 1996 (03.09.1996), see Abstract.	1-23
A	US 5,829,522 A (Ross et al.) 03 November 1998 (03.11.1998), see Abstract.	1-23
A	US 4,649,996 A (Kojicic, deceased et al.) 17 March 1987 (17.03.1987).	
A	US 5,310,001 A (Burns, Sr. et al,) 10 May 1994 (10.05.1994).	

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/25545

Continuation of B. FIELDS SEARCHED Item 3:

EAST

search terms: membrane, filter, screen, shear sub, safety sub, shear pin; seal ring, plastic ring, latch, inner tube, perforated tube, retrievable, releaseable, resusable